8-2015

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Meat Science 106 (2015) 25–30

Contents lists available at ScienceDirect

Meat Science

journal homepage: www.elsevier.com/locate/meatsci

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ARTICLE INFO

Article history:
Received 20 May 2014
Received in revised form 10 December 2014
Accepted 20 March 2015
Available online 30 March 2015

Keywords:
Beef
Breed
Longissimus
Iron
Magnesium
Zinc

ABSTRACT

The objective of this study was to evaluate sire breed effect on mineral concentration in beef longissimus thoracis (LT) and investigate the correlations between beef mineral concentrations and carcass and palatability traits. Steer progeny ($N = 246$) from the Germplasm Evaluation project—Cycle VIII were used in this study. In addition to carcass traits, LT was evaluated for mineral concentrations, Warner–Bratzler shear force, and palatability traits. A mixed linear model estimated breed effects on mineral concentrations. No significant sire breed ($P \geq 0.43$) or dam breed ($P \geq 0.20$) effects were identified for mineral concentrations. Pearson correlation coefficients were calculated among mineral concentrations, carcass, and sensory traits. Zinc concentration was positively correlated ($P \leq 0.05$) with total iron ($r = 0.14$), heme iron ($r = 0.13$), and magnesium ($r = 0.19$). Significant ($P < 0.05$) correlations were identified between non-heme or heme iron and most traits in this study. Magnesium concentration was correlated with all carcass and palatability traits.

1. Introduction

Total beef consumption in the U.S. decreased 15% between 1980 and 2000 and was followed by a decrease from 12.7 to 11.4 billion kg per year between 2002 and 2011 (USDA-ERS, 2014). One of the major contributing factors to this trend is health concerns about fat intake from red meat. However, beef is an excellent source of protein and dietary iron, zinc, and magnesium and should not be viewed only from the fat content perspective. Beef contains the highest amount of iron and zinc of meats commonly consumed in the U.S. (Carpenter & Clark, 1995; USDA-ARS, 2010). In addition, the porphyrin ring of heme iron and the protein in beef can promote the absorption of iron or zinc; therefore enhancing their bioavailability (Stipanuk, 2006).

Beef mineral concentrations vary among individuals and are affected by various physiological, environmental, and within breed additive genetic factors (Doyle, 1980; Duan et al., 2011; Mateescu et al., 2013; Mateescu et al., 2013; Zarkadas et al., 1987). Few studies have evaluated mineral concentrations across several sire and dam breeds of cattle. In one study (Doornenbal & Murray, 1981), the effect of sire breed, from a sampling of *Bos Taurus* breeds, on mineral concentrations was reported to be small. In addition, little information is available in regard to the relationships between beef mineral concentrations and carcass and palatability traits (Casas et al., 2014; Garmyn et al., 2011; Mateescu, Garmyn, et al., 2013). Understanding of the relationships between mineral concentrations and other traits in beef cattle could be valuable for selective breeding to improve the nutritional value of beef.

The primary objective of this study was to evaluate the effect of diverse *Bos Taurus* or *Bos Taurus* × *Bos Indicus* composite sire-breed (Hereford, Angus, Brangus, Beefmaster, Bonsmara, and Romosinuano) on total iron, non-heme iron, heme iron, zinc, and magnesium concentrations of beef longissimus thoracis (LT). Our second objective was to examine the correlations among these five measures of minerals with beef carcass and palatability traits.

2. Materials and methods

All animal procedures were reviewed and approved by the U.S. Meat Animal Research Center (USMARC) Animal Care and Use Committee.

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http://dx.doi.org/10.1016/j.meatsci.2015.03.020
0309-1740/

2.1. Animals and sample collection

Detailed information for animal management, sample collection, and processing can be found in Wheeler, Cundiff, Shackelford, and Koohmaraie (2010). Briefly summarized, steer progeny resulted from artificial insemination mating of Angus or MARC III (1/4 Hereford, 1/4 Angus, 1/4 Red Poll, and 1/4 Pinzgauer) dams with Hereford, Angus, Brangus, Beefmaster, Bonsmara, or Romosinuano sires (Table 1). Data from cattle in this study were obtained from 246 steers harvested in 2002 ($n = 116$) and 2003 ($n = 130$) in Cycle VIII of the Germplasm Evaluation program at USMARC. The male calves were castrated within 24 h of birth. All steers were fed a maize and maize silage based diet and harvested in a commercial facility when they were approximately 427 days of age. The wholesale rib was obtained and transferred to the meat laboratory at USMARC approximately 36 h postmortem. The rib was separated into ribeye roll, lean trim, fat trim, and bone. The ribeye roll was vacuum packed, aged at 2 °C until 14 days (2002) or 15 days (2003) postmortem and frozen at −30 °C. A rib steak from approximately the 8th rib was sent to Iowa State University and stored at −20 °C until mineral concentration analysis.

2.2. Evaluation of carcass and palatability traits

Assessment of carcass and palatability traits was described in Wheeler et al. (2010). Briefly summarized, frozen steaks were thawed at 5 °C for 24 h and then cooked on a conveyorized electric belt grill to a final internal temperature of 71 °C. Separate cooked steaks were used to evaluate Warner–Bratzler shear force or trained sensory panel assessed tenderness, juiciness, and beef flavor intensity for palatability. After cooling for 24 h at 4 °C, Warner–Bratzler shear force was measured on six round cores (1.27 cm diameter) removed parallel to the orientation of the muscle fibers within each steak. The sensory traits were evaluated on a descriptive 8-point scale (8 = extremely tender, juicy, or intense to 1 = extremely tough, dry, or bland) by a trained panel of eight members. Retail product was predicted from lean trim, fat trim, and short ribs as described by Shackelford, Cundiff, Gregory, and Koohmaraie (1995).

2.3. Total iron, zinc, and magnesium analysis

At Iowa State University, steak samples were thawed over a 24-hour period in a 4 °C walk-in cooler. All glassware used was washed in 1 M hydrochloric acid and rinsed with deionized water prior to use. Analytical samples were collected from the center portion of each steak, weighed (~1 g, recorded to 0.001 g), and placed into a 50 ml centrifuge tube to which 10 ml of deionized water was added. This mixture was homogenized for 20 s with a Kinematica Polytron. Mineral concentrations in beef samples were determined according to the method modified from the AOAC official method 999.10 (Jorhem & Engman, 2000). Wet digestion was performed on 5 ml of homogenized sample to which 5 ml concentrated nitric acid and 2 ml deionized water were added. This solution was heated on a heating block at 60–70 °C until clear. After cooling, the digested solution was diluted to a volume of 25 ml with deionized water. Total iron, zinc, and magnesium concentrations were determined with an atomic absorption spectrometer (Perkin Elmer, Waltham, MA). A separate ~1 g sample from the same steak was used to measure non-heme iron with a spectrophotometric assay according to procedures of Rebouche, Wilcox, and Widness (2004). Heme iron concentration was calculated by difference between total iron concentration and non-heme iron concentration.

2.4. Statistical analysis

Statistical analysis was carried out with SAS (SAS Inst., Inc., Cary, NC). The descriptive statistics were generated using PROC MEANS. Extreme mineral concentrations were removed from the dataset (iron > 8.0 mg/100 g, $n = 3$; zinc > 8.0 mg/100 g, $n = 24$; magnesium > 20.0 mg/100 g, $n = 2$; non-heme iron > total iron, $n = 1$). The mineral concentration least squares estimate of the mean for each breed was calculated using a mixed linear model (PROC MIXED in SAS) that included sire and dam breeds as fixed effects; lipid percentage (2.09 to 11.78%), final weight (428.2 to 689.5 kg), and animal age (range 389 to 462 days) as covariates; and year as a random effect. Additionally, linear relationships between mineral concentrations and other traits were evaluated using PROC CORR in SAS to calculate Pearson correlation coefficients.

3. Results and discussion

3.1. Carcass characteristics and palatability

The descriptive statistics for carcass traits, palatability traits, and LT mineral concentrations are presented in Table 2. Sire breed effects on carcass, yield, and palatability traits were reported by Wheeler et al. (2010).

3.2. Breed effect on mineral concentration

The means for LM total iron, non-heme iron, heme iron, zinc, and magnesium concentrations were 3.44 mg/100 g, 0.86 mg/100 g, 2.59 mg/100 g, 4.10 mg/100 g, and 16.42 mg/100 g, respectively, which were consistent with values reported previously (Gerber et al., 2009; USDA-ARS, 2010). Our finding of 69.3% of the total iron being heme iron is consistent with previous reports of heme iron comprising more than 60% of total iron in beef (Valenzuela, Lopez de Romana, Olivares, Morales, & Pizarro, 2009). No significant sire breed ($P \geq 0.43$) or dam breed ($P \geq 0.20$) effect was observed for the concentration of total iron, non-heme iron, heme iron, zinc, or magnesium after adjusting for animal age, intramuscular fat, and final body weight (Table 3).

Similar results for breed effect on mineral concentrations of beef were reported in a previous study. Doornenbal and Murray (1981) evaluated the effect of Charolais, Simmental, Limousin and Chianina sire breeds on the concentration of iron, zinc, magnesium, copper, calcium, sodium, and potassium in three muscles. They reported that the breed of sire differences were small and not significant, except for calcium and sodium (which were not evaluated in this study). They also found a significant interaction between muscle and breed of sire. For example, the LT from Chianina sired cattle had significantly ($P < 0.05$) higher calcium concentration than the LT from Charolais sired cattle. Similarly, sodium was significantly lower in the LT of Limousin sired cattle than the LT of the other sire breeds. In contrast, sire breed differences for sodium

Table 1
Distribution of steers by sire and dam breed.

	Sire breed						
Dam breed	Hereford	Angus	Brangus	Beefmaster	Bonsmara	Romosinuano	Total
Angus	23	0	23	24	24	21	115
MARC III	21	24	22	19	22	23	131
Total	44	24	45	43	46	44	246

Table 2
Overall means for carcass traits, palatability traits, and mineral concentrations.

Trait	Mean	*SD*
Final weight, kg	554	52.5
Hot carcass weight, kg	345	34.5
Adjusted fat thickness, cm	1.07	0.498
KPH fat, %[a]	2.2	0.61
Ribeye area, cm^2	82.3	8.05
Marbling[b]	501.5	71.64
Retail product yield, %[c]	61.5	3.31
Fat yield, %[c]	24.3	4.02
Warner–Bratzler shear force, N	37.3	7.08
Tenderness[d]	5.7	0.55
Juiciness[e]	5.5	0.30
Beef flavor intensity[f]	4.6	0.39
Total iron, mg/100 g[g]	3.44	1.789
Non-heme iron, mg/100 g[g]	0.86	0.518
Heme iron, mg/100 g[g]	2.59	1.878
Percent heme iron, %	69.3	20.8
Zinc, mg/100 g[g]	4.10	0.675
Magnesium, mg/100 g[g]	16.42	1.153
Lipid, %[g]	4.38	1.435
Dry matter, %	28.3	1.92

[a] Kidney, pelvic, and heart fat estimated as a percentage of hot carcass weight.
[b] 400 = Slight^{00}, 500 = Small^{00}, and 600 = Modest^{00} (USDA-AMS, 1997).
[c] Predicted from wholesale rib dissection (Shackelford et al., 1995).
[d] 1 = Extremely tough, 4 = slightly tough, 5 = slightly tender, and 8 = extremely tender.
[e] 1 = Extremely dry, 4 = slightly dry, 5 = slightly juicy, and 8 = extremely juicy.
[f] 1 = Extremely bland, 4 = slightly bland, 5 = slightly intense, and 8 = extremely intense.
[g] Based on wet weight of raw beef.

were not observed in diaphragm muscle. In goats, Park (1988) found no difference in iron, manganese, copper, and zinc concentrations or iron/zinc ratio in the LT of two genders of two breeds of goats. Similarly, Littledike, Wittum, and Jenkins (1995) observed that liver iron concentration did not vary among breeds of cattle. Liver zinc concentration, however, was different between Limousin and Pinzgauer cattle, but not among the other breeds. While we did not identify breed effects on these five mineral concentrations within LT, it is possible for mineral concentrations to be influenced by genetics which vary within breed (Casas et al., 2014; Duan et al., 2011; Mateescu, Garrick, et al., 2013; Mateescu, Garmyn, et al., 2013). In a large study in lambs, Pannier et al. (2014) identified significant effects of sire type on iron ($P < 0.01$) and zinc ($P < 0.05$) concentrations in LT.

In addition to breed, several other environmental and physiological factors have been reported to affect beef mineral concentrations, such as age, gender, muscle type, and diet composition. Giuffrida-Mendoza, Arenas de Moreno, Uzcátegui-Bracho, Rincón-Villalobos, and Huerta-Leidenz (2007) investigated the mineral concentration variation of LT in water buffalo and Zebu-influenced cattle. They found that both zinc and magnesium concentrations went up with an increase in animal age (evaluated at 17, 19, and 24 months of age). Iron concentration, however, had an interaction between species and age. In this study total iron concentration went up ($P = 0.03$) 0.018 ± 0.0084 mg/100 g day^{-1} over the range (73 days) of ages evaluated and heme iron went up at an even faster rate ($P < 0.01$; 0.024 ± 0.0084 mg/100 g day^{-1}). Conversely, non-heme iron went down ($P < 0.01$; -0.007 ± 0.0021 mg/100 g day^{-1}) on a daily basis in this study. In addition, mineral concentrations have been reported to be different among the LT, semimembranosus, and diaphragm muscles (Doornenbal & Murray, 1981). For example, the diaphragm contained significantly higher amounts of iron and zinc than did the LT. Magnesium concentration was higher in semimembranosus than in LT and diaphragm. Beyond those differences, significant differences in the total iron and heme pigment concentrations of beef were found for groups of calves fed different amounts of dietary iron (Miltenburg, Wensing, Smulders, & Breukink, 1992). In our study, the breed effect was tested in a sample population that was raised at the same location, fed a common diet, harvested at a similar age, with a single muscle evaluated. After adjustment for lipid percentage, final body weight, age, and year effects, the concentration of total iron, non-heme iron, heme iron, zinc, and magnesium in beef were all statistically invariant among the breeds (Table 3), which was consistent with previous studies on the breed effect of cattle.

Muscle iron can be divided into heme iron, which is mainly in myoglobin, and non-heme iron, which is mainly in ferritin and iron-containing proteins. While this study does not identify a breed effect in regard to total muscle iron, non-heme iron, nor heme iron, King et al. (2010) found that myoglobin concentration in LT steak was highly heritable ($h^2 = 0.85$) and myoglobin did vary among breeds with myoglobin concentration higher in Gelbvieh, Red Angus, and Simmental than in Charolais and Limousin cattle.

3.3. Correlations with mineral concentration

Pearson correlations among beef mineral concentration and carcass or palatability traits were generally weak but statistically significant ($P < 0.05$). As shown in Table 4, zinc concentration was positively correlated ($P \leq 0.05$) with total iron, heme iron, and magnesium. This positive correlation was not as strong as the positive correlation identified

Table 3
Least squares means estimates of sire and dam breed effect on mineral concentrations of beef LT.

	Trait									
	n	Total iron, mg/100 g[b]	*n*	Non-heme iron, mg/100 g[b]	*n*	Heme iron, mg/100 g[b]	*n*	Zinc, mg/100 g[b]	*n*	Magnesium, mg/100 g[b]
Age, *P*-value		0.03		<0.01		<0.01		0.22		0.58
Final weight, *P*-value		0.70		0.26		0.45		0.27		0.03
Lipid, *P*-value		0.27		0.42		0.15		0.93		<0.001
Sire breed										
P-value[a]		0.69		0.98		0.78		0.95		0.43
Hereford	42	3.61 ± 0.556	42	0.90 ± 0.309	42	2.70 ± 0.818	43	4.09 ± 0.106	44	16.29 ± 0.523
Angus	24	3.15 ± 0.619	24	0.86 ± 0.317	24	2.29 ± 0.861	20	4.15 ± 0.165	24	16.32 ± 0.545
Brangus	45	3.66 ± 0.553	45	0.90 ± 0.309	45	2.76 ± 0.816	41	4.09 ± 0.110	45	16.69 ± 0.523
Beefmaster	43	3.15 ± 0.559	43	0.84 ± 0.310	43	2.30 ± 0.819	39	4.19 ± 0.115	42	16.35 ± 0.526
Bonsmara	45	3.32 ± 0.552	44	0.90 ± 0.309	44	2.48 ± 0.816	42	4.06 ± 0.108	45	16.51 ± 0.523
Romosinuano	44	3.46 ± 0.559	44	0.88 ± 0.310	44	2.58 ± 0.819	37	4.02 ± 0.118	44	16.44 ± 0.525
Dam breed										
P-value[a]		0.47		0.53		0.42		0.29		0.20
Angus	113	3.31 ± 0.516	112	0.90 ± 0.305	112	2.42 ± 0.792	107	4.05 ± 0.072	113	16.35 ± 0.512
MARC III	130	3.48 ± 0.508	130	0.86 ± 0.304	130	2.61 ± 0.786	115	4.15 ± 0.064	131	16.52 ± 0.509

[a] No significant breed differences were observed, $P > 0.10$.
[b] Values expressed on wet weight basis, LS Mean ± SE.

Table 4
Correlation coefficients among mineral concentrations and chemical composition in beef LT[a].

Chemical composition	Total iron		Non-heme iron		Heme iron		Zinc		Magnesium	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
Non-heme iron	−0.04	0.49								
Heme iron	0.96*	<0.001	−0.32*	<0.001						
Zinc	0.14*	0.04	0.08	0.22	0.13*	0.05				
Magnesium	−0.14	0.03	0.22*	<0.001	−0.19*	<0.01	0.19*	<0.01		
Lipid percentage	0.15*	0.02	−0.20*	<0.01	0.21*	<0.01	−0.01	0.88	−0.36*	<0.001
Dry matter percentage	0.22*	<0.001	−0.24*	<0.001	0.27*	<0.001	−0.02	0.77	−0.34*	<0.001

[a] Significant ($P < 0.05$) correlations are identified with an asterisk (*).

between zinc and iron or magnesium reported within a single breed by Mateescu, Garmyn, et al. (2013). Lipid and dry matter percentage were positively correlated with total iron and heme iron concentration while being negatively correlated with magnesium and non-heme iron concentration (Table 4).

No significant correlation ($P > 0.05$) was observed between total iron or zinc and any carcass trait tested (Table 5). Garmyn et al. (2011) reported correlations in the same direction for iron and zinc to marbling, but with their larger study, reported the iron correlation as significantly different from zero.

In contrast, non-heme iron and heme iron were correlated ($P < 0.05$) with most carcass traits and magnesium concentration was correlated ($P < 0.05$) with all carcass traits (Table 5). Non-heme iron was negatively correlated with fat and weight traits, while being positively correlated with muscle and retail product. Whereas, heme iron had the opposite relationship with carcass traits of non-heme iron, being positively correlated with fat and weight traits and negatively correlated with muscle and retail product. The different correlations (opposing sign) between heme iron or non-heme iron and carcass traits were an unexpected result. In comparison, magnesium correlations were quite similar to non-heme iron correlations to carcass traits. Magnesium was negatively correlated with final body weight and hot carcass weight while being positively correlated to LT area and retail product yield. Moreover, higher LT magnesium concentration was correlated with lower percent fat yield, fat thickness, KPH fat, and marbling score. These results were consistent with, but stronger than, the negative correlation between magnesium and marbling score identified by Garmyn et al. (2011).

It is noteworthy that magnesium was correlated with weight, retail product yield, and especially fat-related traits, which supports the role of magnesium in energy partitioning. Magnesium is the second most abundant intracellular divalent cation present in skeletal muscle. It functions as a critical cofactor for many enzymes involved in energy metabolism, fatty acid synthesis, glucose utilization, and ATPase function. Intracellular magnesium deficiency affects the development of insulin resistance and impairs skeletal muscle glucose uptake (Rumawas et al., 2006). Venu et al. (2008) evaluated the effect of maternal magnesium restriction on adiposity, glucose tolerance, and insulin secretion in offspring. Their results showed that offspring had increased body fat percentages, decreased lean body mass and decreased glucose-stimulated insulin secretion, which indicated a long-term effect of magnesium on body adiposity and insulin secretion. One possible mechanism for this relationship is that tyrosine kinase activity is decreased during low intracellular magnesium at the insulin receptor level (Takaya, Higashino, & Kobayashi, 2004). Magnesium deficiency is also linked with a pro-inflammatory effect. In a rat model, feeding a high-fructose and low magnesium diet induced insulin resistance, dyslipidemia, and upregulation of inflammation and oxidative stress biomarkers (Rayssiguier, Gueux, Nowacki, Rock, & Mazur, 2006). From our study, the correlation between magnesium and carcass characteristics provides more evidence for the role of magnesium in energy metabolism.

As shown in Table 6, no correlation was observed between Warner–Bratzler shear force or taste panel evaluated tenderness and total iron, heme iron, zinc, or magnesium ($P \geq 0.10$). However, non-heme iron was negatively correlated ($P < 0.001$) with Warner–Bratzler shear force ($r = -0.22$) with a less strongly associated ($P = 0.07$) relationship identified by the taste panel tenderness scores ($r = 0.12$). Heme iron and total iron were positively correlated ($P < 0.001$ and $P < 0.05$, respectively) with beef flavor intensity ($r = 0.25$ and $r = 0.15$, respectively) and juiciness ($r = 0.22$ and $r = 0.15$, respectively), whereas there were significant ($P < 0.001$) negative correlations between non-heme iron and beef flavor intensity ($r = -0.39$) and juiciness ($r = -0.29$). Additionally, significant ($P < 0.001$) negative correlations were found between magnesium concentration and beef flavor ($r = -0.43$) and juiciness ($r = -0.45$). An earlier study showed that high magnesium was related to strong salty and bitter flavors (Schiffman & Erickson, 1971). Engel et al. (2000) also reported that the absence of calcium chloride and magnesium chloride was associated with a decrease in the bitter taste. Therefore, in our study, the negative relationship between LT magnesium and beef flavor may be connected with that of magnesium and bitter flavor. In addition, a negative correlation was found between magnesium and juiciness. Juiciness has been positively correlated with

Table 5
Correlation coefficients between beef LT mineral concentrations and animal or carcass traits[a].

Carcass trait	Total iron		Non-heme iron		Heme iron		Zinc		Magnesium	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
Final weight	0.09	0.15	−0.18*	<0.01	0.14*	0.03	−0.10	0.12	−0.20*	<0.01
Hot carcass weight	0.10	0.12	−0.20*	<0.01	0.15*	0.02	−0.10	0.14	−0.23*	<0.001
Rib eye area	−0.12	0.06	0.19*	<0.01	−0.17*	<0.01	−0.07	0.31	0.15*	0.02
Retail product yield percent[b]	−0.09	0.17	0.37*	<0.001	−0.19*	<0.01	0.02	0.79	0.38*	<0.001
Fat yield percent[b]	0.08	0.24	−0.38*	<0.001	0.18*	<0.01	0.01	0.90	−0.39*	<0.001
KPH fat[c]	0.04	0.56	−0.20*	<0.01	0.09	0.17	−0.00	1.00	−0.21*	<0.01
Adjusted fat thickness	0.07	0.31	−0.26*	<0.001	0.13*	0.04	−0.01	0.93	−0.27*	<0.001
Marbling score[d]	0.12	0.06	−0.07	0.27	0.14*	0.03	−0.05	0.50	−0.29*	<0.001

[a] Significant ($P < 0.05$) correlations are denoted with an asterisk (*).
[b] Predicted from wholesale rib dissection (Shackelford et al., 1995).
[c] Kidney, pelvic, and heart fat estimated as a percentage of hot carcass weight.
[d] 400 = Slight^{00}, 500 = Small^{00}, and 600 = Modest^{00} (USDA-AMS, 1997).

Table 6
Correlation coefficients between beef LT mineral concentrations and palatability traits[a].

Palatability	Total iron		Non-heme iron		Heme iron		Zinc		Magnesium	
	r	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value	*r*	*P*-value
Warner–Bratzler shear force	−0.02	0.81	−0.22*	<0.001	0.05	0.40	−0.05	0.45	0.01	0.54
Tenderness[b]	−0.01	0.93	0.12	0.07	−0.04	0.55	0.11	0.10	−0.09	0.16
Beef flavor intensity[c]	0.15*	0.02	−0.39*	<0.001	0.25*	<0.001	0.12	0.07	−0.43*	<0.001
Juiciness[d]	0.15*	0.02	−0.29*	<0.001	0.22*	<0.001	0.07	0.27	−0.45*	<0.001

[a] Significant ($P < 0.05$) correlations are denoted with an asterisk (*).
[b] 1 = Extremely tough, 4 = slightly tough, 5 = slightly tender, and 8 = extremely tender.
[c] 1 = Extremely dry, 4 = slightly dry, 5 = slightly juicy, and 8 = extremely juicy.
[d] 1 = Extremely bland, 4 = slightly bland, 5 = slightly intense, and 8 = extremely intense.

intramuscular fat percentage as well as marbling (Jackman, Sun, Allen, Brandon, & White, 2010; Thompson, 2004). Similar to the relationship between magnesium and juiciness, a negative correlation was observed between magnesium and both intramuscular fat (Table 4) and marbling (Table 5) in our study. Magnesium concentration was also correlated negatively with LT dry matter percentage (Table 4), which indicates a possible role of magnesium in reducing water loss during storage.

Garmyn et al. (2011) evaluated the linear relationship between total iron, zinc, and magnesium concentrations and sensory traits in over 1500 samples. Consistent with our results, they found no correlation between total iron or zinc and Warner–Bratzler shear force or overall tenderness. However, in their study all three minerals were positively correlated with beef flavor and juiciness. Magnesium was also negatively correlated with Warner–Bratzler shear force (Garmyn et al., 2011). The large sample size used in their study likely enhanced their power to detect such correlations as different from zero.

4. Conclusions

No differences in mineral concentrations were observed in progeny of Hereford, Angus, Brangus, Beefmaster, Bonsmara, and Romosinuano sire or Angus and MARC III dam breeds of cattle in this study. Thus, these breeds have similar abilities to store total iron, non-heme iron, heme iron, zinc, and magnesium in the LT under the production system used in this study. Interestingly, the concentration of zinc was correlated with that of iron and magnesium, which may indicate concordant regulation. Different correlations (opposing sign) were identified between non-heme iron or heme iron concentrations and most other traits evaluated in this study. Magnesium had the strongest correlations with carcass, tenderness, or palatability traits and total iron had positive correlations to beef flavor and juiciness. This study may be useful for choosing breeds in a breeding strategy to improve carcass or beef palatability attributes with limited effect on beef mineral concentrations.

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